RECURRENT TETRAHEDRAL DEFORMATIONS AND INTERCONTINENTAL TORSIONS.

By B. K. EMERSON.

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Starting a long time ago to write a review of a very interesting and remarkable book I have woven so much of my own musings with the text that I may not well put upon the author the responsibility therefor.

The book in question is "Die Entwickelung der Kontinente und Ihere Lebewelt. Ein Beitrag zur Vergleichenden Erdgeschichte; von Dr. Theodor Arldt, Oberlehrer an der Realschule in Radeberg, mit 17 Figuren und 23 Karten." Leipzig. Wilhelm Engelmann. 1907. 729 pp., large 8°. It is a ponderous volume comparable to Walther's "Einleitung" or Suess' "Antlitz der Erde," but more systematized, and condensed to the limit; so that an exceedingly great amount of painstaking and acute research, covering many diverse fields, is brought into remarkably small compass.

Just two thirds of the book is devoted to a biogeography of the past and the present. After chapters on method comes a general survey of the distribution of plants and animals in the present and Cenozoic, in the Mesozoic and in the Paleozoic, with discussions of their evolution and many "Stammbäume" to summarize this evolution.

The principal purpose of the study is to get all the light which the distribution and probable migrations of the different classes of animals and plants can throw upon the evolution of the continents. A first chapter takes a position adverse to the so-called "permanence of the continents." Only certain large portions of the great ocean seem to have been permanent.

This section is illustrated by a full and clear chart of the biological provinces and regions and five charts which show the migrations of the families of the vertebrates, and ends with two valuable

paleontological chapters which give the first appearance and duration of each of the large groups of plants and animals. In these tables the part of the earth's history before the beginning of life is assumed to be to the part since as 5 to 3.

The second or geological section of the book begins with a condensed systematic discussion of the geological data for the determination of the outlines of the former continents and a comparison of these data with those derived from the distribution of animals.

These sections take up the larger part of the volume and then four short chapters on Ice periods; times of volcanic activity; mountain formation, and transgressions prepare for the central idea of the book, viz.: the statement in tabular form of the cycles of the evolution of the earth as given below and the explanation of the same as due to a succession of tetrahedral deformations, producing broad elevated continents and small oceans; and spherical recoveries, causing broad transgressions of the ocean with low lands.

To his table of the geological cycles here presented I have added the statements regarding the changing carbonic acid content in the air, and the changes in climate and evolution, drawn largely from the papers of Chamberlin which are cited below.

The author accepts the tetrahedral deformation of the earth as the basis of the explanation of these cycles.

The law of least action, he explains, demands that the somewhat rigid crustal portion of the earth keep in contact with the lessening interior with the least possible readjustment of its surface. As a tube collapses into a triangular prism a shrinking sphere tends by the law of least action to collapse into a tetrahedron, or a tetrahedroid, a sphere marked by four equal and equidistant triangular projections; and the earth with its three about equal and equidistant double continental masses triangular southward with three intervening depressed oceans triangular northward, its northern ocean and southern continent, with land everywhere antipodal to water, realizes the tetrahedroid status remarkably. When repeatedly in former geological ages ocean waters separated Europe and Asia, the agreement with hypothesis was still more marked. Gravity observations and geodetic measurements agree therewith, even giving for Asia a larger tetrahedroid surface than for Europe, and many other geological homologies point in the same direction.

Table of Geological Cycles.

Archæan Cycle.	Algonkian Cycle	Early Paleozoic Cycle.	Middle Paleozoic Cycle.	Late Paleozoic Cycle.	Mesozoic-Cenozoic Cycle.
Archæan	Algonkian	Cambrian to Ordovician	Silurian to Middle Devonian	Middle Devonian to Early Permian	Triassic to present
Brief tetrahedral elevations Long continued	spherical	depressions			
	Archæan mountain system	Lower Algonkian Transgression with peneplanation	Hebridian and Laurentian mountain systems (Algonkian)	Cambrian Transgression	Brazilian and Green mountain systems	Silurian Transgression	Caledonian mountain system	Devonian and Carboniferous Transgression	Hertzinian and Appalachian mountain systems	Mesozoic Transgression, broken by Laramide Revolution with mountain making and many volcanoes but without extensive glaciation	Cordilleran and Alpine mountain systems
Absorption of CO_2 Greenville Limestone	Emission of granite and CO_2	Absorption of CO_2 Huronian Limestone	Emission of diabase and CO_2	Absorption of CO_2 Cambro-Silurian Limestone	Emission of diabase and CO_2	Absorption of CO_2 Wenlock and Niagara Limestone	Emission of diabase and CO_2	Absorption of CO_2 Onondaga and Mountain Limestone Coal Beds	Emission of porphyry porphyrite melaphyr CO_2 volcanic dust	Absorption of CO_2 Chalk and Nummulitic Limestone Coal Beds	Emission of basalt trachyte phonolite, CO_2 volcanic dust
	Archæan Glaciation		Precambrian Glaciation		Ordovician Glaciation		Devonian Glaciation		Permian Glaciation		Glacial period
			Arid variable climate	Warm equable climate	Arid and variable climate	Warm equable climate	Arid and variable climate	Warm equable climate	Arid and variable climate	Warm equable climate	Arid and variable climate
			Depleted Marine Life	Expansion of Marine Life	Depleted Marine Life	Expanded Marine Life	Depleted Marine Life	Expanded Marine Life	Depleted Marine Life	Expanded Marine Life	Depleted Marine Life
	Great revolution in high latitudes		Great revolution in low latitudes						Great revolution in high latitudes		Great revolution in low latitudes

The axis of figure of the forming tetrahedroid chanced not to coincide with the axis of rotation and the latter gradually shifted from near Behring Straits to its present position, which is one of stable rotational equilibrium. This happened in pre-cambrian time.

At this point comes the interesting novelty in the tetrahedral theory. The development of the tetrahedral form from shrinkage would proceed but a little way when rotation would tend to reproduce the spheroidal form. The tetrahedroid shape would be pushed beyond the strength of the material and collapse would ensue, with reassumption of a more spherical form. In a long period of rest the crust would be recemented and strengthened and the continued escape of heat would then tend to develop the tetrahedroid again and rotation would again restore the spheroid.

This is brought into connection with the six great geologic cycles as follows: The solidified crust becomes by interior shrinking slightly tetrahedral. This involves elevation with glacial conditions, large continents, inner crustal tensions, foldings, fissuring, mountain-making and outpouring of lava. Through this fissuring the crust becomes weakened, the tangential force of rotation becomes predominant, restoring the spheroid; great transgressions of the oceans then intervene while mountain-making and volcanic activity approach a minimum. In the relatively long time of submergence and quiet the faults and fissures are sealed up by the circulating waters and the earth becomes again rigid enough to permit the oncoming of a second period of tetrahedral deformation. The oceans are deepened and contracted, the continents elevated and enlarged with mountain-making and this becomes again the cause of a glacial period and volcanic activity. This cycle is several times repeated.

We are now in a period of deformation, as is shown by the marked tetrahedral features of the earth, the sinking of the Pacific coral region, the abundant volcanic and earthquake activity and the just passed glacial period.

The author assumes the nebular hypothesis and Arrhenius's theory of the condensed-gaseous condition of the earth's interior, and noting the unimportance of the present equator for the structure of the earth, and the great importance of the band going through the three Mediterraneans; that is, THE Mediterranean and the East

and West Indian Seas, he assumes that the equator once went parallel with this band and about 10° south of it, with the north pole at Behring's Straits and the axis at right angles to the ecliptic. Then a band on either side of this equator including "the zone of the intercontinental seas" or of the above three Mediterraneans, because of the powerful tidal influence in the early ages, would be a zone of distortion and rupturing during the crust-forming period and of weakness since. This is Lowthian Green's twinning plane.[1] The author follows Green also in assuming that in addition to this equatorial flood-tidal fracture zone and at right angles to it would run a meridional ebb-tidal fracture zone, which would pass through the two points where the old and new equators bisect each other and would be the meridian bordering the Pacific and including Australia and Antarctica.

This equatorial fracture zone he takes to explain the Mediterranean zone and the transverse fracture zone to explain the permanence of the Pacific.

For the establishment of this position he cites that part of the reviewer's article on the tetrahedral earth[2] where Green's theory is explained at length but not accepted. The later postulate of the author that the earth has many times taken the tetrahedral form, collapsed, and become again so rigid that it could again suffer tetrahedral deformation would seem to militate against a continuous inheritance of weakness in this region.

The zone of fissuring remained a plane of weakness and the greater elevation of the northward parts of the three triangular land masses or coigns, or "shields" bringing them to move in a longer circle and so to lag behind, caused a westward torsional motion of these three portions of the coigns as compared with the parts south of the aforesaid zone.

The author accepts the suggestion first made by the reviewer[3] that the depressed ocean bottoms brought by sinking to move along shorter radii must exert pressure against the west sides of the con-

[1] T. Lothian Green, "Vestiges of a Molten Globe," Honolulu, 1875, Pt. II, 1887.

[2] "The Tetrahedral Earth and the Zone on the Intercontinental Seas." Pres. Add., *Bul. Geo. Soc. of Am.*, Vol. II., 1900.

[3] Loc. cit., p. 65.

tinents, and makes it the basis of his classification of mountains and of his explanation of the chains around the Pacific.

He follows Reyer and Suess in explaining the chains of southern Asia as "Abflussbogen," outflow chains due to flowage down a slope from the elevated coign or shield of "Angara land" or Manchuria. The festoon chains along the east of Asia are "Zerrungsbogen," dragged chains due to the separation of ocean bottom and land because of the eastward drag caused by the depression of the ocean bottom and its differential eastward motion. These terms are discussed later in this paper.

Andes and Cordillera are "Stauungsbogen," heaped up chains" caused by eastward pressure of the sunken Pacific ocean bottom and this pressure is transferred eastward to cause the eastward curving Antilles and the submerged South Georgean eastward curve south of South America.

The sinking of the Caribbean is an accessory cause of the Antilles and the sinking of the Mediterranean the sole cause of the chains from Alps to Caucasus.

It is very interesting that the hypothesis of a tetrahedral earth can be thus utilized in the fundamental explanations of the past conditions of the earth and this may be said to add to the arguments in favor of the hypothesis.

Wholly novel is the suggestion that tetrahedroid may have alternated repeatedly with the spheroid. The earth is thus a composite photograph of several tetrahedra, as indicated in the title of this paper.

In the following the reviewer presents (1) a different explanation of the chains in the Mediterranean zone as due to northward flow (rather than to thrust from the sinking of the Mediterranean), an explanation which was advanced in his presidential address, and (2) a new exposition of the torsional movements which differs from the book here reviewed as well as from the above-cited article of the reviewer.

The Torsional Movements.

The very lucid map of the book showing the tetrahedral deformation is here reproduced (Fig. 1) and the reviewer has added

arrows at equidistant points on the map, in order to make clear the following explanation.

Under the first arrow, Europe-Africa has not suffered torsion and remains, as Green's map shows, closely occupying the place of the original tetrahedral elevation. There has been no torsional motion between Europe and Africa, because of the small size of the former and the large size of the latter and the parallel relations of the

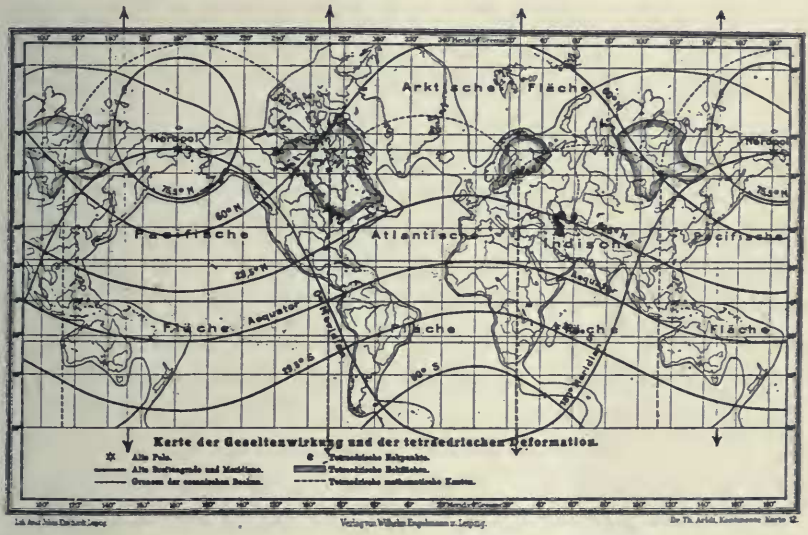

FIG. 1. Map showing the tetrahedral deformation.

old and new equators. Underneath the second arrow is Australia and since the whole of western Australia is unfolded Archæan this meridian may represent the original and symmetrical position of the second tetrahedral elevation, and its north part (Asia) being abnormally large has lagged westwardly, until in its last position it coalesces with Europe. The map shows by a dotted line the depressed area north of the Caspian—the former northward extension of the Indian Ocean.

The next arrow shows that North America is in or near its true tetrahedral position, while South America has drifted eastward, due to its lesser elevation and the excessive eastward thrust of the exceptionally broad South Pacific sea bottom, which was an abnormally large depression from the beginning. Thus the largest elevated land

mass has made the only lag, the antipodal largest depressed area has made the only advance. This lessens by one third the amount of torsional movement heretofore assumed in the hypothesis and locates it differently.

Africa is thus the torpid center of the earth in this sense and not in the more adventurous dream of Sacco,[4] that it is the inert center from which the continents have drifted away in great floes as a recoil when the Moon was torn from the bed of the Pacific, an event probably never seen by any "glimpse through the corridors of time."

I will not suppress the fanciful suggestion that if Angara land—the Asian nucleus, or Manchurian shield—was formed (with Australia as its southern apex) and then drifted westward, in a later deformation Angara land in its new position may have grown southward, producing the triangular peninsula of India, which is a dwarf Africa, in shape a true south apex of a tetrahedral coign.

The reviewer has elsewhere suggested that the westward movement of these old lands, to wit, Asia, and in lesser degree North America, may have been not wholly a slipping on some deep plastic layer but rather in part an advance by the crumbling down of eastern parts of these shields and upfolding of western parts.

This may explain why Angara land lies on the eastern part of Asia and the Canadian shield on the eastern part of America and connect with the disappearance of an old land east of our Atlantic coast-line. This westward advance of the Asiatic mass may explain the great westward faulting around Angara land, especially along its western border.

An inspection of the map shows broad bands of land submerged slightly, which extend on curved lines southeasterly from the three south apices to the Antarctic continent. This suggests a westward torsion of the three coigns as wholes on the Antarctic continent independent of the differential movements of the parts among themselves, but dependent on their varying size and distance from the space. As favored by Reyer and Suess the abnormal elevation of Angara Land might furnish a low slope down which a superficial layer could slide, the shear being lessened by internal heat or the moisture of strata newly risen from the sea, and aided by tidal

[4] "Les Lois fondamentales de l'orogenie de la Terre."

strains and earthquakes, thus forming the festoon of outward-curving chains along the east coast of Asia. Their curved out-spreading fronts greatly resemble the curving frontal lobes of a continental glacier. In several of these curves the rearland sunken blocks are wanting and this rearland sinking can best be explained, when it occurs, as a subsequent result of the stretching and not as a cause of the mountain building.

Angara Land by its great and elevated mass developed these eastward-curving chains along its east border, aided by the deep sinking and the eastward tendency of the Pacific bottom, and by its westward lagging motion it brought its south border opposite the deep Indian ocean bottom and made this the slope for the south-ward-curving south Asian chains, and left the north border of Australia facing the deep Pacific, thus making the northward slope for the great northward curves of Oceanica. At the junction of these three bands is the great virgation of southern Asia emphasized by the three strange four-toed fault-bordered[5] islands, Borneo, Celebes, and Gilolo.

It is the home of the tornado, the earthquake and of the great lines of volcanoes like Krakatoa and Tomboro. It is the "Knoten Punkt" of the earth for all natural phenomena, where plant and animal life reach their most remarkable culmination and face each other in the most remarkable contrasts across Wallace's line.

In the same way the eastward movement of South America enabled it to present its north shore to the deepest Atlantic and formed the slope for the northward movement of the northward curving Antilles while the compression of the great Pacific and the small size of North America was sufficient to prevent the formation of southward-moving curves in North America like the Himalayas in Asia.

The Northward Flow of the South European Chains

The south Asian chains flow south as long as the Indian Ocean depression is before them and Angara Land behind them, but long before they come near the influence of the Mediterranean all the great chains between the Caucasus and the Pyrenees turn and flow

[5] Hans v. Staff, *Zeit. Deutsch. Ger. Gesell.*, 1911, p. 180.

north away from the great mass of Arabia-Africa. Later sinking has occurred in part of the rearland and that these sinkings were later is shown because they have often included parts of the chains themselves as in the Crimea. These sinkings could not then be the cause of the chains. Indeed, in the Ægean also they are known to be much more recent than the chains. The land moved northward in many divaricating folds, with enormous overthrusts far beyond the competency of the sinking Mediterranean even in the most favorable sections. The abnormally small size of the European nucleus aided in this formation of the slope on which these wrinkles could form and move northwardly in great overlaps which have been the special study of Swiss and French geologists for many years.

While the depression of the Pacific by combining extensive wedge action and eastward momentum from the sinking seems to be a vera causa for the Andes and Cordillera, this is not possible for the sinking of the Mediterranean where the force acting northwardly, the rotational effect of the earth is wanting, and so there is no momentum, and being much smaller the wedge effect would be insufficient to make the enormous overthrusting of the Alps. Moreover the chains go west across Spain and east across Asia Minor, extending in great loops northward far beyond the influence of the sunken blocks of the Mediterranean and Black Sea. The great virgation of the Alps and the sigmoid curves of Spain, the Carpathians and Balkans suggest a movement far north into narrowing latitudes which crumpled the curves, while the Asian chains moving in the opposite direction in an expanding area deploy flow-like, as does a glacier moving out on a plain. These chains from Spain to the Caucasus lie along the crest and northern slope of the old equatorial protuberance and when the equator was transferred south to its present position this projection was unsupported and sunk, flowing down northwardly in great convex loops. The slow southward transfer of the equatorial protuberance dependent on the movement of the pole prevented corresponding southward-moving chains, except perhaps in the case of the Atlas range, or perhaps here the sinking of the Mediterranean may have been effective. If the transfer of the equator be found indefensible the mass of Africa

itself may have been raised abnormally like Angara Land to form the similar slope down which the northward sliding occurred.

The three intercontinental seas are not all alike, but the true Mediterranean is contrasted with the Caribbean and East Indian areas.

The two latter are placed on the borders of the Pacific at the points where the old and new equators intersect near the Galapagos Islands and Sumatra (see the map), and the former where the equators are most widely separated. In the two the east-west torsions have moved the continental segments most apart, so that mountain curves could flow north toward the equatorial depths to form their curved mountain boundaries, and their three deep depressions.

The classical Mediterranean has mountain chains which have moved not toward oceanic depths but toward the continental center, and it is placed directly opposite to the center of the Pacific, while the other two are where both equators intersect the volcanic border of the Pacific. By an unexplained coincidence it has three deeps like the others.

The Mediterranean has been the center of civilization. The other two have been rather the opposite, more centers of seismic and of cyclone activity and the United States has unfortunately acquired foothold in both.

The Mediterranean zone has always been a more continuous ocean (the Tethys of Suess) in transgression periods than in tetrahedral periods, therefore it has been many times built up and destroyed. Therefore its being maintained as equator till the Tertiary has made these cycles possible.

The Migration of the Poles

This transfer of the pole and equator to the new position, in whole or in part, in the late Tertiary agrees with the independent suggestions of many botanists and zoologists in explanation of the Tertiary and modern distribution of plants and animals.

Arldt rejects this Tertiary deformation and places the transfer of the pole in the Archæan, because it would, he believes, have been attended by more enormous mass movements even than those of the Tertiary. He is discussing the matter from the standpoint of the

Kant-Laplace hypothesis; and the hypothesis of Arrhenius (which was independently deduced by Arldt) of an interior of highly comprimated and heated gas essentially a solid of great density and elasticity, and yet the stupendous movements of the Mediterranean zone and of the Pacific zone of fire in the Miocene seem sufficiently great to meet the demand even of this radical hypothesis.

With the evidence at hand interpreted in accord with the planitesimal hypothesis it is hard to estimate the relative importance of the three great revolutions, the pre-Cambrian, the Permian, and the Pleistocene. It seems probable that they increased in intensity. Would not the tetrahedroid be realized in larger and larger degree as the mass increased and solidified, and be antagonized less quickly and efficiently by the spheroidal tendency as rotation became slower? Are we not now passing slowly out of an intense glacial period?

Again would the present equator be so unimportant geologically if it had been with all its tidal strain where it is now, since the early Archæan?

The geological map of the earth shows many contrasts and harmonies dependent on this mode of origin.

Africa is the torpid continent with *no* border folded mountain chains because it met the average tetrahedral conditions with the minimum of resistance.

South America and Australia are balanced in relation to the two similar Mediterraneans, each with a large unfolded Archæan area facing Africa and *one* folded mountain chain farthest from Africa. These chains are, however, of unlike origin and character, the Australian an outflow chain of the Asian festoon type; the South American a compression chain of the Cordilleran type. This is because the broad abnormally depressed Pacific is the predominant factor acting with compression against South America and with tension from Australia.

North America is the normal continent, with two bordering mountain chains. In the Permian upfolding the Appalachians flowed west from an elevation east of the present coast, of which there is evidence in the strata, as the beds mainly grow coarser toward the east. The beds flowed west down a virtual slope crumpling and curving (stauend) where they met an old land in the

Adirondacks, and dying out in faint waves against the flat unfolded forelands to the southwest. The Atlantic is specially bordered by Rias Coasts, indicating sinking. The Cordillera on the west were caused by the tangential thrust of the sunken broad Pacific.

Europe is a dwarf continent. It began with the formation of the Urals in the east like the Appalachian, but stands in relation to the unique Mediterranean, and is abnormally overthrust from the south with a minimum addition to its area.

Asia is a giant continent in size and shows a maximum of motion and of outflowing mountain chains.

India is a dwarf counterpart of Africa. They both have the continental notch on the west, and a big island off to the southeast, but the volcanic area is on the west in India, while it is on the east in Africa.

Attention is called to the consideration that the tetrahedral hypothesis does not stand or fall with the hypothesis of the suggested movement of the poles. The flattening at the poles and bulging in the lower latitudes is favorable to such movement, and if this tetrahedral configuration has been repeated the movement of the pole may be cumulative. It is recognized that the amount 22° is beyond the maximum motion of 15° suggested by G. H. Darwin as possible, and yet the argument of Green does not seem to me to have been completely met and the "zone of the intercontinental seas" seems to plead strongly for such a movement.

Darwin's paper has been quoted recently as proving mathematically that migrations of the pole sufficiently great to be of geological importance have not occurred. What Darwin really said is this: "We have thus clearly a state of things in which the pole may wander indefinitely from its original position." By a succession of considerable changes it might migrate in a devious way some 10° or 15° from its geographical position at consolidation. He then goes on to make the supposition by way of illustration and as if it were a possible case that in the glacial period the north pole stood where Greenland now stands. He goes on to say: "This would require extensive and numerous deformations and if the continents are assumed to be permanent would it not be almost necessary to give up any hypothesis which involved a *very wide* excursion of the

poles?" This would rule out pendulations of the north pole into the present southern hemisphere and back again, but need not be called a mathematical proof that the pole may not have moved in several stages 15°–20° from a point north of Behring's Straits to its present position. But even this is not absolutely necessary because we may make the assumption that the Pleistocene tetrahedral deformation was so irregular that the southern half of one lobe (Africa) was so abnormally raised that the Alpine chains flowed north to partly submerge Europe and when the collapse came the sinkings caused the three-lobed Mediterranean and the Black Sea, as the China seas were formed.

In accordance with the idea of multiple working hypotheses we may examine and compare the other current theories concerning the genesis of continents, and see if any reason exists why the tetrahedral tendency may not coëxist with all other agencies of deformation and sometimes partially control the result.

See postulates a thrust from the suboceanic area against or beneath the continental areas, getting the force from oceanic leakage by which abundant sea water penetrating the subcrusted lava froths it so that, expanding, it is thrust beneath the coastal border and raises it in mountain chains. It is difficult to understand why, if the sea bottom cracks, and water penetrates to the deep-seated lavas, the expansive force should not relieve itself through the fissured area whence the waters come, rather than propagate itself many hundred miles beneath coastal areas and form inland mountain chains.

From the deflection of the pendulum at the various stations of observation in the United States Heyford concludes that "isostatic compensation" exists in a superficial earth shell about seventy-one miles thick, so that a short suboceanic vertical section is of equal weight with a long continental one of the same base. If unloading by erosion takes place, the unloaded area will expand because decrease of pressure favors those chemical and solution changes which increase bulk, and vice versa the loaded area will contract because increase of pressure will tend to favor those chemical and solution

changes which decrease bulk and increase density. Thus equilibrium will be destroyed without producing a common level, and a slow surface creep of the lighter and higher land areas toward the sea will ensue, and as a result beneath this surface creep a great slow undertow from the ocean areas toward the continents. The undertow being attached continuously to the surface strata, and the two moving in opposite directions, there must be shearing between them or crumpling of the surface layers, which are free to relieve part of the tension by folding. Therefore the mountain chains are a short distance inside the continental borders and parallel to them.

Willis accepts essentially the conclusions of Heyford, but utilizes exclusively the lower layer underthrust from the oceanic areas. He speaks of a "suboceanic spread," *i. e.*, "the expansion of suboceanic masses within the upper hundred miles of the crust in consequence of the efficiency of stresses due to greater density to direct movements occasioned primarily by molecular or mass changes under varying temperature and pressure."

Much is made of the idea of great areas of habitual elevation and depression. These must be subordinate to the great persistent continental elevations and oceanic depressions.

The rhythmicality is explained by the unproved consensus in the rhythm of several causes none of which are shown to be rhythmical.[6]

The special tendency to collapse when the centers of the coigns rise too high would explain the central seas on the three shields, as the Baltic and Hudson's Bay. It is interesting in this connection that Heyford declares[7] the earth to be a failing body. He reconciles this inward thrust with Suess's idea that the Asian chains flowed seaward by saying that the thrust of the ocean bed beneath the coastal parts of the continents would produce the same effect as an outward superficial motion of the land.

"Gondwana land," he says, "has been carried north with the deep underflow"[8] which passed beneath and wrinkled up the Himalaya. But Gondwana land is a rising and thus a lighter area against which the flow should have impinged and formed mountains on its

[6] "Asia," II., 130.

[7] Heyford, "Geodetic Evidence of Isostacy," *Proc. Wash. Acad.*, VIII., 36–39, 1906.

[8] Loc. cit., p. 133.

south, or if Gondwana land is carried north with the deep underflow Angara land should be carried forward also by the larger Pacific flow.

This underthrust would hardly produce the glacier-like lobing of the Asian chains so characteristic of the outflow of ice, and would not explain the northward overthrust of the mountains across Europe from the Pamir to the Pyrenees, where the oceanic area is wanting and the thrust must have come from Arabia and Africa. It does not explain the contrast between the festooned Asian chains and the straight American coasts, nor all the complexity of the zone of the intercontinental seas.

Such a band thrust far under the continental mass must have had behind it an enormous force to overcome the resistance to shear (which may have approached the breaking strength of the rocks) over all its broad upper and under surfaces and have surplus force to upfold the many festooned mountain chains of Asia. Indeed this suboceanic spread occupying the greater portion of the hundred miles in depth would have caused vertical elevation of the sea bottom, instead of being transmitted so far inland beneath so small a load. We may contrast with this the superficial movement down a slope having shear only on an under surface softened by an internal heat. This sliding might be carried down a very low slope, solicited as it were, by the constant stresses of the earth tides and occasional earthquake vibrations, especially in soft and water-soaked strata recently emerged from the sea.

The hypothesis as presented by Heyford can, however, coëxist with the tetrahedral hypothesis, since an elevation of the central continental mass would favor the superficial flow and hinder the deep-seated one.

It would seem, however, that for the formation of the earth's largest features much deeper portions of the earth would be concerned than are involved in the compensations of isostacy.[9]

Heyward bases his theory upon the observed fact of isostacy but this fact itself is still sub judice.

Because of the heatgradient we may assume the centrosphere to now consist of gas above the critical point, by compression made

[9] See Chamberlin and Salisbury, "Geology," p. 556, 1904.

heavier than iron, and from its way of conducting earthquake waves, more rigid than steel, and with rigidity increasing centerward.

We may accept it as highly probable that a condition of approximate isostacy exists over the area of the United States, with compensation of the lighter land and deeper adjacent sea areas within perhaps one hundred miles of the surface.[10] It, however, remains to be proved whether this is true of other continents or a constant condition of any continent. This must be reconciled with the existence of long periods of peneplanation when the base-leveled surface is not raised as the load is removed but often submerged beneath the waters of a transgressing sea.

The theory of isostacy must also meet the fact that the lavas of midoceanic regions are nowhere ultrabasic, but rather intermediate between basic and subacid. They range from rare nepheline basalts (SiO_2 39, sp. gr. 2.9) to rhyolite (SiO_2 76, sp. gr. 2.4). The average is basalt and andesite (SiO_2 53, FeO = 20, su. gr. 27–2.95). While all the masses of terrestrial metallic iron, the diamontiferous olivine rocks (sp. gr. 3.2–3.5), the greatest accumulations of magnetite, the greatest areas of heavy "norites with titanic iron borders" are found in the old highlands.

The diamond-bearing rocks would seem to have come from great depths which could furnish great pressures, unless the Ovifak irons and the diamond-bearing Vaalite are planetesimals.

The postulates of the planetesimal hypothesis are distinctly favorable to the tetrahedral hypothesis. The possible considerable irregularity in the accumulation of the matter would supply a needed condition for any such deformation and especially for a deformation into a somewhat irregular and one-sided tetrahedroid.

The storage of outgoing heat in an outer shell which should promote the formation of a plastic stratum along which flow could take place would be an additional favorable condition.[11]

It is quite possible that the planetesimal hypothesis may be found to supplement rather than supplant the nebular hypothesis.

The impact hypothesis, suggested by the great multitude of

[10] J. F. Heyford, "Figure of Earth and Isostacy," Coast Survey, 1909.

[11] Chamberlin, "Geology," p. 539.

spiral nebulæ comes as a welcome antecedent to either hypothesis, and permits a great latitude in the amount of heat and volatilization which may be assumed as the result of a given collision.

At one extreme the conditions postulated by the usual planetesimal hypothesis may prevail; at the other with a maximum of volatilization conditions approaching the older theory may be present, a momentum derived from nebular contraction adding itself to and modifying that caused by impact, so that in most favorable cases even rings either temporary or permanent might be formed. We can perhaps follow a satellite formed by the condensation of such incandescent matter mixed with solid fragments in greater or less quantity through to the present probable condition of the earth or other planets, more easily than one made up of a cold and heterogeneous mass of discrete planetesimals; and equally well or better imagine it to assume in some degree the tetrahedral form.

Chamberlin presents the calculation that shrinkage stresses of the whole globe would support domed elevations on the earth only eight miles high, but this is on the assumption that the earth material is "firm crystalline rock."[12] But the crushing strength of the deep-seated earth material should be taken as that of the steel dies of the crushing machine rather than that of brittle rock (or indeed twice that of steel as deduced from the rapidity of earthquake transmission), which would give a value for this elevation of the proper order for even more than the continental protuberances. Indeed Chamberlin in the same page seems almost to have contemplated the very rhythmical mechanism we have assumed when he says: "It is as if the shrinkage stresses accumulated to the full strength of the stress-resisting power of the whole sphere and then collapsed."

There are good grounds to believe with Chamberlin[13] that the greater earth movements affect all quarters of the globe together, that they are periodic and that the "ocean basins become progressively deeper and more capacious, while the protuberances become more protuberant," that "in the process of periodic adjustment of the earth to its internal stresses, portions of the crust are thrust

[12] "Geology," I., 556.

[13] "Diastrophism as the Ultimate Law of Correlation," *Jour. Geo.*, XVII., 685, 1909.

up to heights notably above the plane of isostatic equilibrium, and that these portions gradually settle back toward equilibrium."[14] That "the conditions prerequisite to baselevelling involve a high degree of stability through a long period of time." The great baselevellings and the great sea transgressions which are little more than alternative expressions for the same thing have as their fundamental assumption a sufficient stability of the surface to permit baselevelling to accomplish its ends.

Chamberlin states these stages as (1) That of climacteric baselevelling and sea transgression favoring the expansional evolution of shallow water life and wide migrations and comminglings leading to cosmopolitan faunas.

(2) The stages of retreat which are the first stages of diastrophic movement after the quiescent period marked by abundant erosion and deposition of deep soil mantles, limited life area, and lessened migration.

(3) The stages of climacteric diastrophism and greatest sea retreat marked by restrictional evolution of shallow water faunas, increased land deposits, broadest continents, diversity of land surfaces and climatic extremes.

(4) The stages of progressive degradation and sea advance, marked by the reëxpansion of the narrowly provincial shallow water faunas formed in isolated areas in the previous period.

The tetrahedral hypothesis thus presents itself as a welcome introduction or preliminary to Chamberlin's suggestion of diastrophism as the foundation of correlation, since it gives a cause for a rhythmical recurrence of short periods of diastrophism with long intervening periods of quiescence. In harmony with this hypothesis is the remarkable generalization of White and Knowlton,[15] that a uniform warm humid climate extending beyond the polar circles has been the rule from early paleozoic, interrupted by relatively short periods of climatic extremes when great glacial areas coëxist with a torrid zone.[16]

[14] Putnam and Gilbert's pendulum studies indicate that the part of our continent uplifted in late Tertiary is still above the level of equilibrium.

[15] *Science*, XXXI., 760.

[16] Variations of the sun's heat have been adduced as cause of varying climate and even the passage of the solar system through cold areas in space.

The remarkably interesting new book by Professor Chamberlin[17] gives what I had suggested above as desirable and feasible, to wit, a more nebular trend to the planetesimal hypothesis. It makes clear the reality of the forward rotations of a satellite by the interaction of elliptical rather than circular orbits, and builds up with convincing clearness such a simple spiral nebula as would evolve into our solar system. He lets the approaching star exert its disrupting agency on our sun, then larger by the mass of the planets, as a tidal attraction which sets free the enormous expansive energy of the sun itself so that great masses of incandescent matter—exaggerated protuberances—were thrown off, and thrown off in rotation because of the unequal character of the expelling force. Such masses form the knots on the arms of the spiral nebula and by contraction on cooling initiate the planets. By exaggerating—which he does not do—the size of these knots in relation to the final planet's we get all the advantages without many of the disadvantages of the old nebula theory.

He then goes on to develop the thesis that the major influence in producing the larger inequalities of the earth's surface has been *the variation in the rate of rotation of the earth;* thus proposing a supplement or substitute for the tetrahedral hypothesis.

Starting with the idea that rotation must have had alternate increases; when the equatorial band would bulge and the polar areas flatten; and decreases when the equatorial band would flatten and the polar areas bulge, there would be a secular seesaw motion between the rising and sinking areas along circular fulcrum lines at 30° N. latitude and 30° S. latitude. The tensile stresses during elevation in the polar areas would be relieved (on the law of least action) by three fissures radiating from the north pole at 120° from each other and ending at the fulcrum line. The tensions produced during the following equatorial expansion would be relieved by 6 fissures divaricating 2 and 2 from the three ends of the set of fissures above defined, and meeting 2 and 2 at the opposite fulcrum line and

Indeed a certain parson is reported by Lockyer to have claimed that there might be areas in space in which miracles were possible and that the earth may have passed through such an area at the beginning of our era.

[17] "The Origin of the Earth," 1916.

at the three ends of the corresponding set of fissures from the south pole, dividing the equatorial band into six about equilateral triangles, set saw-tooth-wise. Three alternating ones would be placed base to base with the three north polar triangles above defined. The three intervening ones would be placed base to base with the three triangles formed around the other pole by three lines similar to those first mentioned and drawn to the south pole from where the zigzag line touched the southern fulcrum line. The six quadrilaterals made each of two triangles base to base on the fulcrum lines; three touching the north and three the south pole, and interlocking saw-tooth-wise across the equator would by their see-saw motion on the fulcrum lines relieve the stresses rising from the variations in the rotation. It is further assumed that all other stresses, as shrinkage, tides, erosion effects, would be localized as elevations along these lines and reach a maximum with special protuberances at their intersection. These lines become then of great width and are the nuclei of the continents and are called yield tracts rather than fissure lines.

The formation of basaltic columns and especially the ball and socket structure, with protuberances rising at the points where three cracks meet, and connected by lower ridges along the cracks, is taken as an instructive illustration of how the rising in ridges along these fissure tracts would occur and the especially marked protuberances at their junction would be formed, and is considered almost a proof that the process has really taken place. There seems, however, only partial resemblance between the two cases. The tensile strains are here alternating; in the basalt coincident and continuous. The trap column furnishes an analogy only for the action at the poles and only for the first half of the cycle, and it is not exact there. As expansion proceeds tension is relieved by three fissures radiating from the pole but this tension and fissuring are not equal along the three lines to the next angles as in the trap but decrease outwardly to zero. When the second half of the cycle begins it may first close up the fissures and then bring the polar regions into a state of compression with maximum at the pole, a state of things not occurring in the trap, where there is no compression and so no elevation. This compression might relieve itself by folding or mashing along lines of weakness with little regard to the 120° law or to the former fissure

lines, which might be sometimes cemented so as to be lines of greatest strength. It would not need to fold at the same places in successive compression periods. The other points where three lines join on the fulcrum line are wholly unlike the corresponding points on a trap column. They are indeed points where three almost nonexistent lines meet, since tension and motion die out as the fulcrum line is reached. During the subsequent compression period also these points are places of minimum compression and so of minimum elevation, but they are the points where the greatest protuberances—the continental shields—must be.

It is, moreover, hard to see how the three polar fissures can exert any influence across this dead space to locate the corresponding fissures which stretch across the equator, since the maximum tension by which these fissures are formed is at the far distant equator where it would be more probably relieved by fission along three lines at 120° (after the manner of trap), radiating from centers on the equator and at convenient distances apart, rather than by lines or bands slanting across the equator 8,000 miles apart.

I have seen where the triassic sandstone has been stripped off the trap and found no elevation at the junction edges of the surface of the columns or depressions at their centers and the same is true of mud cracks. There is rather a slight depression where the columns join. The ball and socket structure is a deep-seated one, and the ridges along the edges of adjacent columns and the elevations at the corners are not upthrusts in any sense. The six-sided column has first formed by shrinkage and rupture, and no further action takes place across the ruptured surfaces, then later shrinking and consequent fissuring inside each column separately have produced a "spheroidal parting" inside each individual column and it is this curved parting which forms the apparent hollow when the column falls in pieces, or when several columns have been eroded to a common level forms the adjacent hollows bounded by the intervening ridges and corner projections. There is no trace of a longitudinal motion of the central part of the basalt column up or down or sidewise. Indeed the blocks into which the column breaks will be concave upward for a while and then be followed by a double concave block and then will be convex upward for a time and then be fol-

lowed by an exfoliating spherical mass as large as the cross-section of the column. There are samples of all these shapes in the collection at Amherst.

Thus no support can be drawn from analogy of the ball and socket structure of trap for the explanation of the large earth features as a result of variations in rotation.[18]

It is further difficult to see how this oscillation on unknown but very long period and of unknown but very slight amplitude can "attract" the other deforming agencies and form bands of fissuring and elevation radiating at 120° and culminating where the movements pass through the zero point. The amplitude and period and total duration of these oscillations are left wholly indeterminate and as we exaggerate the nebular character of the original knot and minimize the mass and period of falling and variation of falling of the planetesimals, which is the cause of variation in rate, we may have conditions where the whole effect would be small or even negligible. It is further interesting to note that when a line of tension is drawn from the south pole to the fulcrum line at the south point of Australia, it is then continued northwest with the full width of Australia across the East Indies, bending north in Asia with the full width from Afghanistan to eastern China, and there is no corresponding northeast line to divide the Pacific. In the same way the line drawn from the south pole to South America goes northwest with the full width of South America and bends north in North America with a width from southern California to Georgia and there is no northeast line to divide the Atlantic. In the case of Africa the treatment is different, and the line from the south pole is made to branch, although at much too small an angle at the south point of Africa, and the branches to run up the two coasts to Afghanistan and the Atlas mountains and then converges to the north pole and a hypothetical ocean is made to occupy the area from Arabia to Scandinavia. It is more consistent and consonant with the other arrangements to have made Africa a "yield tract" exactly analogous to South America and Australia. The line along the east border of the continent, closely parallel to the corresponding line

[18] Polished cross-sections of trap columns show a wholly homogeneous texture. R. B. Sosman, "Types of Prismatic Structure in Igneous Rocks," *Jour. Geol.*, XXIV., 228, 1916.

along the east border of the other continents, would be the base line of this yield tract as far as Somaliland and the tract would run northwest to meet the fulcrum between the Atlas Mountains and Asia Minor and its northern meridional part would include Europe and have on its right a diminished ocean in the depressed Aralo-Caspian Basin, and unlike the others, a northeast band across Arabia naturally separating this small ocean from the Indian Ocean. In this case each "yield tract" has a Mediterranean in its center and Italy in the center of the one trends closely parallel with Cuba and Sumatra in the center of the others.

We may further notice that the elevated fissure tracts that are thus built up are coincident with the tetrahedral elements of the earth's framework. We may welcome any new light on this dark subject and feel sure that the rotational and tetrahedral theories are supplementary and not antagonistic, the latter would seem however to be the preponderant and precedent influence since it would tend to make the two poles as unlike as possible, as is the case: while the rotational hypothesis acting on a reasonably homogeneous earth would make the poles essentially similar and symmetrical, as is not the case. The tetrahedral hypothesis would demand continents widening to a maximum where they surround the polar ocean, as is the case. The rotational theory would demand three northern continents tapering northwardly into points directed toward the corners of an arctic continent at the north pole, which is not the case. The tetrahedral hypothesis centers on the common explanation of the 4 great coigns. The other has two explanations for them: one for the south polar continent, another for the other three, placing them where the supposed causative forces are at their zero point. The drawing of six circular oceans leaves much to be desired and one superfluous ocean surrounds the north pole.

A great elliptical ocean is drawn covering quite closely the present seat of war and with a major axis on the Berlin-Bagdad Railroad. An ultra-pacifist would readily see the desirableness of submerging this region, at least temporarily.

We may go further and say that if the five great depressions were originally made in part at least by the tetrahedral deformation they would have located the five great gyrals or "permanent highs"

as they are assumed to have been located by the rotation process, and would have gained the advantage of any sorting action of the air and water currents in concentrating the heavier matter over the sea bottoms and the lighter over the land. This would tend to increase the tetrahedral depressions and promote the breaking down of the elevations and the spherical recovery.

The chapter is introduced by a diagram from Darwin showing that the tidal stresses are eight times as great in the central as in the equatorial regions. This dynamical basis for the theory is largely non-existent, since as shown by Barrell[19] the citation is from an earlier and erroneous calculation later corrected by Darwin, who shows that the central stresses are only two and two thirds greater than the equatorial.

Barrell says further concerning the theory:

> "It is not clear that earth strains due to the causes invoked could initiate such a primary segmentation, in fact calculations on the stresses which the reviewer has made to test this sub-hypothesis pointed to quite a different method of yielding. The distribution of continents and oceans does not accord very closely with it, and the evidence of isostacy does not indicate that the density differences between continents and ocean basins reach below the outer fiftieth of the earth's radius. This hypothesis of juvenile shaping should therefore be accepted with much reserve and does not appear to be as well supported as are the conclusions of the previous chapters."

The remarkable paper by Professor Lane[20] fits all the crevices of the tetrahedral theory. There is a surface layer for orogenic purposes, a deeper plastic (asthenospheric) layer to facilitate flowage, a deeper layer for epeirogenic purposes, indeed, for tetrahedral purposes and provision for periodic collapses. A nut with its acute distal point and its obtuse proximal end is a suggestive model of the tetrahedral earth; a triangular beechnut would have been simply perfect.

Two tables have been published giving the periods of elevation and depression of the North American continent. The table of Shimer is based largely on the geological maps of Chamberlin and

[19] *Science*, XLIV., p. 244, 1916.

[20] A. C. Lane, "On Certain Resemblances between the Earth and a Butternut," *Scientific Monthly*, 1915, p. 132.

Salisbury[21] and that of Schuchert[22] averaging the results of his extensive and valuable work on the paleogeography and paleometeorology of North America. The two tables are in substantial agreement with the table of Arldt (see p. 447). The larger disturbances given by Schuchert agree with Arldt's cycles except that the Grand Canyon revolution is local and the Caledonian cycle is less marked in North America than the others. He brings out very clearly the brevity of the elevation and the great length of the intervening times of depression.

"Granting all this," says Schuchert[23] (after reviewing all the theories to explain the "climates of geological time" except the tetrahedral hypothesis), "there still seems to be back of all these theories a greater question connected with the major changes in paleometeorology. This is: What is it that forces the earth's topography to change with varying intensity at irregularly rhythmic intervals? . . . Are we not forced to conclude that the earth's shape changes periodically in response to gravitative forces that alter the body form." The tetrahedral hypothesis is certainly trying to force this same conclusion.

The idea of a spherical recovery and extensive transgression and exceptionally equable climate far poleward would take away largely the need from the biological side of many assumed continental connections across the deep oceans as bridges for migrations. Their migrations could take place during equable climates by long circuitous land connections extending far poleward, and would remove many apparent conflicts with the supposed tetrahedral configuration of the earth, which appear in many restorations of early geological periods. This was written in 1913 and the important and authoritative article by Mathew on "Climate and Evolution,"[24] brought so full confirmation of this suggestion and so strong condemnation of the indiscriminating bridge building which has been customary for

[21] H. W. Shimer, "Broader Features of the Geological History of North America," *Technology Quarterly*, Vol. XX., p. 287, 1907.

[22] "Textbook of Geology," Pt. 2, p. 980, 1915.

[23] "Climates of Geologic Time," Pub. Carnegie Inst., No. 192, p. 289.

[24] W. D. Mathews, "Climate and Evolution," *An. N. Y. Acad. Sc.*, Vol. 24, pp. 171–318.

fear, as Colman says, "some stray marsupial might get his feet wet in migrating to a new habitat," that I copy here his thesis and conclusions.

"THESIS.

"1. Secular climatic change has been an important factor in the evolution of land vertebrates and the principal known cause of their present distribution.

"2. The principal lines of migration in later geological epochs have been radial from Holarctic centers of dispersal.

"3. The geographic changes required to explain the present distribution of land vertebrates are not extensive and for the most part do not affect the permanence of the oceans as defined by the continental shelf.

"4. The theories of alternations of moist and uniform with arid and zonal climates, as elaborated by Chamberlin, are in exact accord with the course of evolution of land vertebrates, when interpreted with due allowance for the probable gaps in the record.

"5. The numerous hypothetical land bridges in temperate, tropical and southern regions, connecting continents now separated by deep oceans, which have been advocated by various authors, are improbable and unnecessary to explain geographic distribution. On the contrary, the known facts point distinctly to a general permanency of continental outlines during the later epochs of geologic time, provided that due allowance be made for the known or probable gaps in our knowledge.

"SUMMARY OF EVIDENCE.

"The geologic evidence for the general permanency of the abyssal oceans is overwhelmingly strong. The continental and oceanic areas are now maintained at their different levels chiefly through isostatic balance, and it is difficult to believe that they could formerly have been reversed to any extensive degree. The floor of the ocean differs notably in its relief from the surfaces of the continents, and only in a few limited areas is the relief suggestive of former elevation above sea-level. The continental shelf is so marked, obvious and universal a feature of the earth's surface that it affords the strongest kind of evidence of the antiquity of the ocean basins and the limits beyond which the continents have not extended. The supposed evidence for greater elevation in the erosion channels across its margin have been shown to be better interpreted as due to 'continental creep.' The marine formations now found in continental areas have all been deposited in shallow seas. No abyssal deposits have ever been certainly recognized among the geologic formations of the continental platform."

It would thus seem possible that with the continuous escape of heat and volatile bodies a slight constant tendency of the earth toward tetrahedral deformation might combine with the other more

active forces and like the action of rotation in deflecting rivers prove effective when the other forces are balanced against each other.[25]

The continuous escape of juvenile waters suggested by Suess may have promoted shrinking and have thus aided in regularly increasing the depth of the ocean basins.

And only part of this juvenile water may have been absorbed in the hydration of minerals so that the amount of the ocean waters may have increased. We may also accept the conclusions of Walther that the earlier oceans were shallow and that the great and increasing deepening of the great permanent ocean bodies which the tetrahedral theory demands began with the Triassic, since all paleozoic survivals were shallow water forms.

Indeed the slow process by which the agglomeration of planetesimals condensed into a globe of double the rigidity of steel would permit the postulated repeated recurrence of periods of tetrahedral deformation and spheroidal collapse, at first barely discernible among the other deforming agencies but gradually becoming relatively more important until at last in the grand Tertiary cycle the deformation should be so great as to cause the final stage of the movement of the pole to its present place and impress the strong tetrahedral features on the face of the present earth.

Finally one might say there is a certain three-fold hierarchy in earth movements—orogenic or mountain making; epeirogenic or plateau making; tetrahedrogenic or continent making.

[25] It should be distinctly borne in mind that the tetrahedral deformation is not a crystalline action any more than is the formation of hexagonal trap columns. Indeed the tetrahedral deformation of a spherical mass is exactly like the hexagonal deformation of an extended mass. Both are governed by the law of least action in a very similar way. There are isometric tetrahedral crystals and there are six-sided hexagonal crystals. They are often perfect and perfectly embody a physical law. The other cases represent a tendency and act only when the remaining agencies are balanced and should be judged by their best results. One should no more overlook the tetrahedral tendency because it is often imperfectly realized than the hexagonal tendency in all shrinking bodies.